UNO DE LOS AUTORES DEL HALLAZGO ES ARGENTINO

Descubren objetos que van a mayor velocidad que la luz

PARIS (Por **Jean-François Augereau**, de "Le Monde", especial para **Clarín**). – Dos astrónomos, el argentino **Félix Mirabel** y el mexicano **Luis Rodríguez**, acaban de hacer una observación sorprendente: **descubrieron materia que viaja a una velocidad superior a la de la luz**.

Lo que los investigadores observaron –y publicaron en el último número de la revista Nature– fue la eyección, por parte de dos astros, de chorros de materia a velocidades aparentemente superiores a la de la luz. Es la primera vez que este fenómeno, ya detectado en los límites del Universo, se observa "cerca" (en términos astronómicos) de la Tierra. Esto permitiría a los astrofísicos disponer de un modelo para tratar de comprender el funcionamiento de los **quásares**.

El hallazgo fue bautizado **GRS 1915 + 105**, lo que identifica un punto en el mapa del cielo, perdido en la inmensidad de la Vía Láctea.

Mirabel y Rodríguez hicieron esta observación en marzo. Tras las consolas del radiotelescopio del National Radio Astronomy Observatory de Socorro, en el estado norteamericano de Nuevo México, observaron la curiosa fuente de rayos X descubierta en 1992 por un satélite franco-ruso.

En ese momento, este hallazgo no impactó a la comunidad astronómica. El GRS 1915 + 105 fue estudiado sin que se lo pudiera asociar con un astro que emite luz en el terreno visible. En cambio, su observación en el terreno de los rayos X y las ondas de radio reveló enormes variaciones de luminosidad que por momentos lo hicieron el objeto más brillante de la Vía Láctea.

Por eso, Mirabel y Rodríguez decidieron apuntar hacia él las antenas del radiotelescopio. Golpe de suerte: sin previo aviso, GRS 1915 + 105 se puso a "escupir" ante sus ojos, en direcciones opuestas, dos potentes chorros de materia condensada. Un fenómeno aún más sorprendente cuando los cálculos demostraron que esos chorros de materia se alejaban del corazón de GRS 1915 + 105 a una velocidad muy superior (125%) a la de la luz.

La sorpresa tenía motivo: la velocidad de la luz –300 mil kilómetros por segundo– es una constante del universo que ninguna ley transgrede.

Esas velocidades "supralumínicas" ya habían sido medidas en los límites del universo, en esos objetos lejanos y misteriosos llamados quásares, y que los astrónomos sospechan que son núcleos activos de galaxias que están siendo devoradas por agujeros negros presentes en su centro.

Pero estas velocidades fuera de toda norma no traducen la realidad de los hechos. Son resultado de distorsiones, de ilusiones que se deben a la relatividad, algo análogas a las que se encuentran en el terreno de la óptica. Sin embargo, los astrofísicos saben manipularlas para salir de ese mundo de apariencias y encontrarse con lo real. Es lo que hicieron Mirabel y Rodríguez al mostrar que la materia escapa de GRS 1915 + 105 a una velocidad precisamente "astronómica": un 92% mayor a la velocidad de la luz. **Nunca se había visto nada igual en nuestra galaxia.**

Para los dos astrónomos, GRS 1915 + 105 sería un sistema de estrellas doble, compuesto de una que gira alrededor de un compañero muy masivo y denso, que podría ser tanto una estrella de neutrones como un miniagujero negro. Debido a la fuerte gravitación ejercida por ese compañero de pequeñas dimensiones –una estrella de neutrones tiene de 20 a 30 kilómetros de diámetro y su densidad es de varios centenares de millones de toneladas por centímetro cúbico– grandes cantidades de materia son arrancadas a la estrella.

En un lapso previsible, esa materia cae hacia el astro central y forma alrededor de él una suerte de anillo, conocido con el nombre de **disco de acreción**, y produce poderosas bocanadas de rayos X. Pero en ciertas circunstancias ese proceso atraviesa períodos de inestabilidad que son el origen de los chorros de materia registrados y de las fuertes emisiones de ondas de radio.

"Sería como un ogro que se ahoga, escupe violentamente después de haber comido demasiado ligero y eructa", graficó un astrónomo.

Todo eso apasiona a los astrofísicos, en la medida en que podría ser análogo en pequeña escala al que se produce con los quásares en las fronteras del universo. Un modelo soberbio al alcance de la mano, al menos para los astrónomos. Para nosotros, simples mortales, GRS 1915 + 105 dista solamente 40 mil años luz de nuestro planeta, es decir, la insignificancia de 400 mil billones de kilómetros.

Traducción: Marta Vassallo

A superluminal source in the Galaxy

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APPARENT velocities greater than the speed of light (superluminal motion) have been inferred for radio-emitting components in a number of distant quasars and active galactic nuclei[1]. These components move away from the central sources (generally thought to be super-massive black holes) at rates that seem to imply velocities greater than *c*. The accepted explanation is that clouds of plasma are ejected in opposite directions from the central source at speeds close to (but less than) that of light, and that relativistic effects lead to the apparent superluminal motion[2]. But the extreme distance of the objects observed so far introduces many uncertainties into this interpretation[3]. Here we present observations of the first apparent superluminal motion ever detected in a source within our own Galaxy. The optical, infrared and X-ray properties[4,5] of the counterpart suggest that the source is either a neutron star or a black hole that is ejecting matter in a process similar to, but on a smaller scale than that seen in quasars. Because of its relative proximity, this superluminal microquasar may offer the best opportunity to gain a general understanding of relativistic ejections seen elsewhere in the Universe.

In the course of a general study of radio counterparts of γ-ray sources we observed with the Very Large Array a remarkable ejection event in the transient source GRS1915+105 (ref. 6). After the observation of strong radio outbursts[7,8], we have followed the large proper motions of a pair of bright radio condensations emerging in opposite directions from a compact core. Figure 1 shows maps of GRS1915+105 at a wavelength of 3.5 cm for seven epochs of observation between 27 March and 30 April 1994. These composite maps exhibit a pair of bright radio condensations (see Table 1) emanating from a flux-variable, compact source. The angular resolution of the observations reported here was 0.2 arcsec, and the positions were determined by absolute astrometry with accuracies of 0.02 arcsec.

In Fig. 2 are plotted for each condensation the angular displacements from the stationary core as a function of time. This Figure shows that the components move away with different apparent speeds, and that both were expelled from the compact source on 19 March 1994 at 20:00±5 UT, when the source appeared brighter than usual in the X-rays[9].

In the following we model this object on the basis of the antiparallel ejection of a pair of condensations moving at speed $\beta(\beta = v/c$, with v being their velocity and c the speed of light),

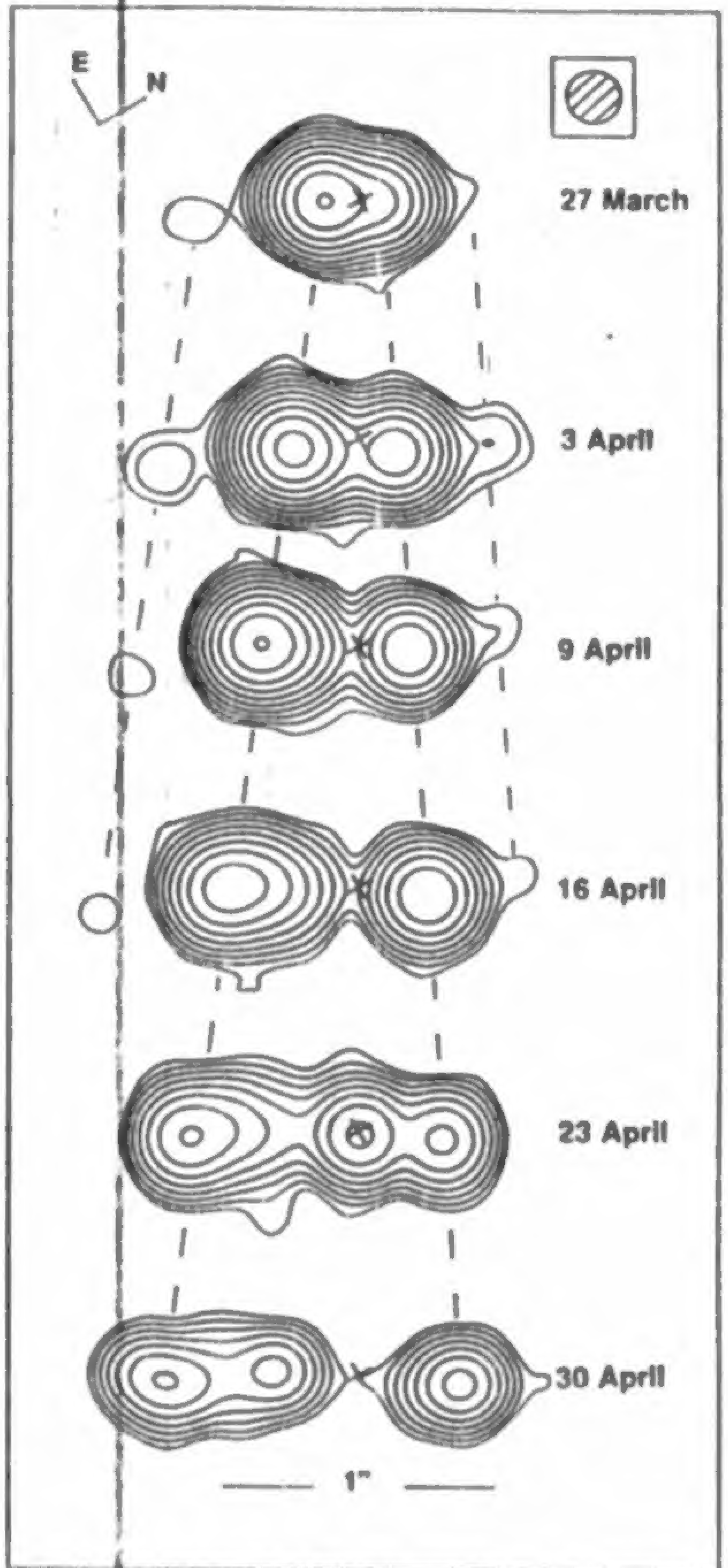

FIG. 1 Pair of bright radio condensations moving away from the high-energy source GRS1915+105. These uniform-weight, self-calibrated VLA maps were made at wavelengths of 3.5 cm for the 1994 epochs shown on the right side of the Figure. The vertical separation between the individual maps is proportional to the interval of time between the observations. Note in the first four epochs the presence of a fainter pair of condensations moving ahead of the bright ones at about the same speed. On 23 April the core flared again, and on 30 April a new southern component appeared. The stationary position of the core at right ascension $\alpha(1950) = 19$ h 12 mm 49.966 s; declination $\delta(1950) = 10^\circ\ 51'\ 26.73''$ ($\pm 0.02''$), which is indicated with a small cross, was determined by absolute astrometry from maps made at times when the core was observed flaring (26 February, 3 March, 18 March and 23 April 1994). The half-power beam width of 0.2 arcsec is shown in the top-right corner. The maps have been rotated 60° clockwise for easier display and the actual orientations of the north and east are also shown in the top-left corner. Contours are 1, 2, 4, 8, 16, 32, 64, 128, 256, 512 and 1,024 times 0.2 mJy per beam for all epochs except for 27 March, where the contour levels are the above in multiples of 0.6 mJy per beam.

TABLE 1 Evolution of the radio condensations at 3.5-cm wavelengths

Date (1994)	Hour (UT)	South component					North component				
		Dist. (")	PA (°)	Flux (mJy)	Size (mas)	p.a. (°)	Dist. (")	PA (°)	Flux (mJy)	Size (mas)	p.a. (°)
24 Mar	14:75	0.08	155	655	60 × 20	167					
27 Mar	16:33	0.14	146	329	50 × 30	121	0.07	330	102	50 × 30	313
03 Apr	15:58	0.24	157	150	90 × 30	140	0.13	313	47	100 × 30	328
09 Apr	15:92	0.36	147	124	110 × 50	148	0.18	331	25	60 × 50	319
16 Apr	13:00	0.45	149	63	210 × 60	156	0.25	326	27	60 × 40	314
23 Apr	12:58	0.59	150	42	230 × 70	160	0.31	327	16		
30 Apr	12:43	0.72	150	36	570 × 80	154	0.37	327	20	90 × 50	340

To derive the spectral indices at different stages of evolution on 24 March and 16 April we also carried out observations at wavelengths of 2 and 6 cm. On 24 March, 3.8 d after the ejection, when the pair of condensations still could not be resolved, the spectral index ($S \propto \nu^{\alpha}$) was -0.49 ± 0.01. On 16 April, when the two condensations had moved apart, both had spectral index $\alpha = -0.84 \pm 0.03$. PA is the position angle of the peak emission with respect to the stationary core, and p.a. of the major axis. Flux density errors are ~5%.

TABLE 2 Multi-wavelength properties of GRS1915+105 and SS433

Source	μ arcsec yr^{-1}	Dist. (kpc)	Veloc. ejecta	Precession of axis	Emission (keV)	L_X (erg s^{-1})	A_V (mag)	M_K (mag)	ΔK (mag)
GRS1915+105	6.4/3.3	12.5	0.92c	Unknown	≤220	3×10^{38}	≥20	−6.0	0.9
SS433	3.2	5.5	0.26c	164 d	≤30	5×10^{35}	7	−5.5	1.1

Symbols used: μ, proper motion; L_X, X-ray luminosity; A_V, absorption at visual wavelengths; M_K, absolute infrared magnitude in the $K=2.2$ μm band; ΔK, observed variation in the infrared K band.

with the axis of the flow making an angle θ with respect to the line of sight of a distant observer. The apparent proper motions of the approaching and receding condensations, μ_a and μ_r, are given[10] by:

$$\mu_{r,a}=\frac{\beta\sin\theta}{(1\pm\beta\cos\theta)}\frac{c}{D} \tag{1}$$

where D is the distance from the observer to the source. The asymmetry in the speeds of separation from the compact core between the southern and northern condensations that is seen in Figs 1 and 2 may be explained as the result of the differential time delay between the approaching and receding components[2], which is expressed by opposite signs in the denominator of equation (1).

Due to relativistic aberration, the ratio of the apparent surface brightnesses (measured at equal angular separations from the core) from twin components moving at high velocities in opposite directions is given[10] by

$$\frac{S_a}{S_r}=\left(\frac{1+\beta\cos\theta}{1-\beta\cos\theta}\right)^{k-\alpha} \tag{2}$$

where α is the spectral index of the radio-emitting components. In the case of continuous jets $k=2$, whereas for discrete condensations $k=3$. Because (as we show below) $\beta\cos\theta=0.323$ and $\alpha=-0.8$ (see legend of Table 1), the flux ratio in the case of twin discrete condensations would be 12, whereas for continuous jets it would be 6. The fluxes listed in Table 1 show that for equal angular separations, the flux ratio between condensations is 8 ± 1. Therefore the asymmetries, exhibited both in the speeds of separation from the compact core and in the flux ratios, allows us (under the assumption of relativistic motions), to identify the southern component as approaching and the northern as receding.

A relativistic upper limit for the distance can be derived from the measured proper motions of the approaching and receding condensations. Equation (1) can be transformed to the equivalent pair of equations:

$$\beta\cos\theta=\frac{\mu_a-\mu_r}{\mu_a+\mu_r} \tag{3}$$

$$D=\frac{c\tan\theta}{2}\frac{(\mu_a-\mu_r)}{\mu_a\mu_r} \tag{4}$$

The product $\beta\cos\theta$ can be determined without knowing the distance. As $\mu_a=17.6\pm0.4$ mas d^{-1} and $\mu_r=9.0\pm0.1$ mas d^{-1}, we find that $\beta\cos\theta=0.323\pm0.016$. This last result implies that $\cos\theta\geq0.323$ or $\theta\leq71°$ and that $\beta\geq0.323$. Substituting the upper limit $\theta\leq71°$ in equation (4) and noting that 1 mas d^{-1} = 5.61×10^{-14} rad s^{-1}, we obtain from relativistic constraints an upper limit to the distance of $D\leq13.7$ kpc, and conclude that the observed motions take place inside the Galaxy.

We have determined the kinematic distance to GRS1915+105 by means of the 21-cm absorption of atomic hydrogen along the line of sight. The source is close to the Galactic plane ($l=45.37°$, $b=-0.22°$) beyond ≥20 mag of optical absorption[4]. In Fig. 3 we show the H I opacities toward the peak continuum positions of GRS1915+105 and toward G45.46+0.06, which is the closest H II region on the sky with known kinematic distance[11]. The column density of H I along the line of sight to GRS1915+105 is $N(\text{H I})=(1.73\times10^{22})(T_s/100\text{ K})$ cm^{-2} (where T_s is the spin temperature), which is 1.42 times the column density along the line of sight to the H II region G45.46+0.06. Because the H II region is at a distance of ~8.8 kpc, assuming a constant H I absorption per unit length places GRS1915+105 at $D=12.5\pm1.5$ kpc, which is consistent with an optical absorption of ~20 mag (ref. 4).

At this distance the proper motions of the approaching and receding condensations imply apparent velocities on the plane of the sky of 1.25 ± 0.15 and 0.65 ± 0.08 times the speed of light. Using equations (3) and (4) we infer that the ejecta move with a true speed of $\beta=0.92\pm0.08$ at an angle $\theta=70\pm2°$ to the line of sight.

A rough estimate can be made for the kinetic energy of the bulk motion of the condensations by assuming that, due to internal motions, all electrons have Lorentz factors $\gamma\approx10^3$ as required to produce the centimetre-wavelength radio emission. Assuming that there is one proton per electron, the total mass m in the condensations is of the order of 2×10^{25} g (~1/3 the mass of the Moon), and the kinetic energy of their bulk motion is $(\gamma-1)\,mc^2$, or 3×10^{46} erg.

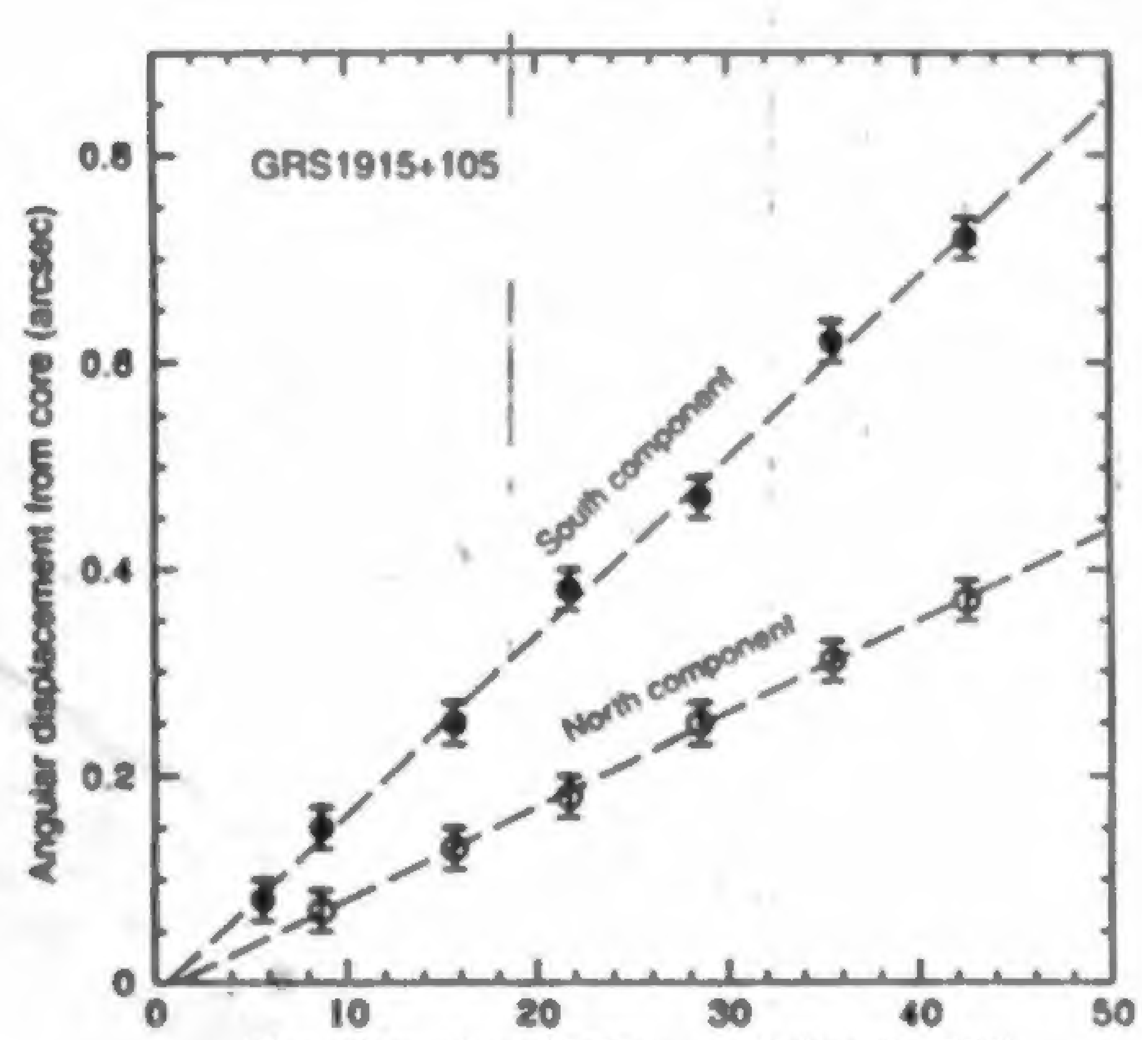

FIG. 2 Angular displacements of the bright radio-emitting components from the compact core as a function of time. The southern condensation (solid circles) appears to move faster than the northern condensation (empty circles). The best fits for the components are, respectively, $\mu_S=17.6\pm0.4$ mas d^{-1} along a direction with position angle $150\pm3°$, and $\mu_N=9.0\pm0.1$ mas d^{-1} along a direction with position angle $330\pm5°$ (empty circles). Both regression lines converge toward the same point on the time axis. This implies that the major pair of condensations was ejected from the compact object about 19 March 1994, at 20:00±5 UT.

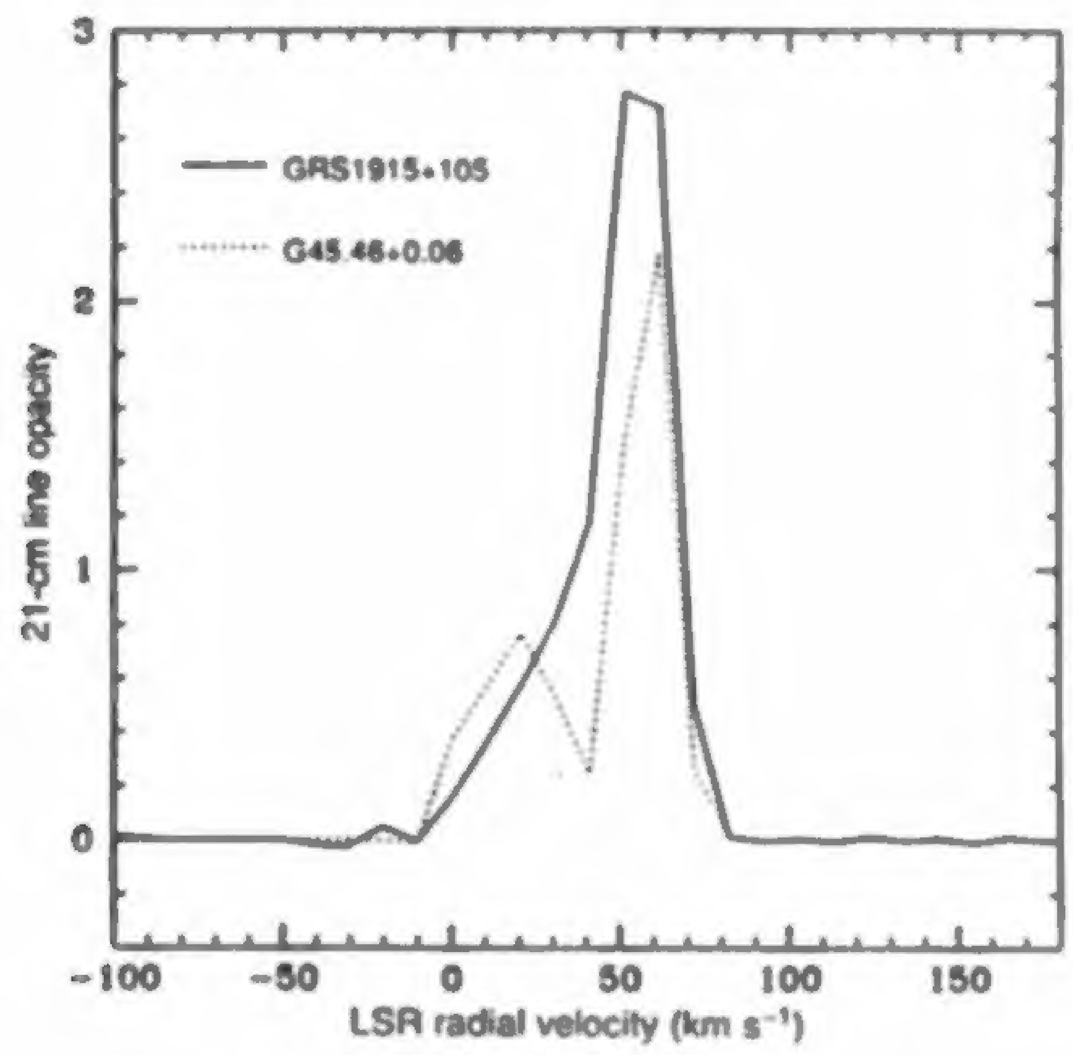

FIG. 3 Opacities of 21-cm line from atomic hydrogen absorption spectra along the lines of sight to GRS1915+105 and to the H II region G45.46+0.06, at a projected distance of 17 arcmin from the high-energy source. These VLA-D observations were carried out on 16 December 1993, when we measured from the high-energy source a continuum flux at 21 cm of 230 mJy. The radial velocity with respect to the Local Standard of Rest (LSR) of $+53.6 \pm 1$ km s^{-1} for G45.46+0.06 obtained from H109α observations[11] places the H II region unambiguously at ~8.8 kpc from the Sun (assuming that the Sun is at a Galactocentric distance of 8.5 kpc). From the additional H I absorption observed towards GRS1915+105 (note the significant excess of opacity at ~+40 km s^{-1} from H I at ~10 kpc) we derive for the high-energy source a kinematic distance of 12.5 ± 1.5 kpc.

The large kinetic energy of the condensations suggests an acceleration mechanism with very large power. From the source size on 24 March, 5 d after the ejection, we estimate that the ejection event must have lasted $\leqslant 3$ d, requiring a minimum power of 1.2×10^{41} erg s^{-1} to accelerate the twin ejecta. This is $\geqslant 400$ times the maximum observed steady photon luminosity of GRS1915+105 (ref. 5), which is 3×10^{38} erg s^{-1}. Because on 18 and 21 March, the measured[9] steady X-ray flux from GRS1915+105 was $\leqslant 10^{39}$ erg s^{-1}, a radiation acceleration mechanism would require an increase by $\geqslant 10^2$ in the source's luminosity some time between 18 and 21 March. We note that the power required for the acceleration of the twin condensations exceeds the luminosity of the soft γ-ray bursts observed in previous years from the same region of the sky[12], which had values of $\sim 10^{40}$ erg s^{-1}. Because of the large position errors of the γ-ray telescopes, the association of GRS1915+105 with one of the only three known repeaters of soft γ-ray bursts is still uncertain[4,12-14].

GRS1915+105 often becomes the most powerful X-ray emitter in the Galaxy. The X-ray light curve[5] observed since its discovery[6] in 1992 shows that, for recurrent periods of several months, it is one of the brighter sources of the sky at energies $\geqslant 20$ keV. At a distance of 12.5 kpc, its mean X-ray luminosity during periods of activity is $\sim 3 \times 10^{38}$ erg s^{-1}, ~10 times the mean luminosity of the classic black-hole candidate Cygnus X-1. The spectra[5,15] of GRS1915+105, with emission up to 220 keV and photon indices that change between -2.5 and -3.0, indicate that the source is a massive stellar remnant (black hole or neutron star).

This superluminal microquasar appears to be a scaled-up version of the famous stellar source of radio jets SS433 (ref. 16), which was believed to be unique in our Galaxy. For comparison, we list in Table 2 some of the overall properties of these two objects. Although the radio properties of GRS1915+105 may appear reminiscent of SS433, the actual velocity of the ejecta and the X-ray luminosity are much larger in GRS1915+105. In particular, the kinetic energy per unit mass of the ejecta, that is proportional to $(\gamma - 1)$, is ~40 times larger in GRS1915+105. However, similar large ratios of 'kinetic' to photon luminosity are found for both sources. Furthermore, in both sources the kinetic energy of the electrons due to the bulk motion of the ejecta is comparable to the high energy cut-off in the X-ray spectra, suggesting strong coupling via Compton scattering.

The study of Doppler-shifted spectral lines in GRS1915+105, as was done for SS433 (ref. 16), would allow the system to be resolved, leading to an independent determination of the distance by a method that has no precedents in astronomy. The Doppler factors (the ratios of observed to emitted frequency (ν_0) for the approaching and receding condensations) are given[10] by

$$\delta_{r,a} = \frac{\nu_{r,a}}{\nu_0} = \gamma^{-1}(1 \pm \beta \cos \theta)^{-1} \tag{5}$$

where $\gamma = (1 - \beta^2)^{-1/2}$ is the Lorentz factor. As we know $\beta \cos \theta$ from equation (3), a determination of either ν_a/ν_0 or ν_r/ν_0 will allow the determination of β from equation (5) and thus the determination of θ and of the distance from equation (4). The spectral lines arising in the approaching and receding components should have mean redshifts of 0.75 and 2.36 respectively (as a result of relativistic effects, both should appear redshifted). Because of strong interstellar absorption, the search for line emission has to be done either in the infrared, where a variable counterpart with magnitude $K(2.2\ \mu m) = 13$–14 was detected[4], or in the hard X-rays.

The observations of this superluminal microquasar, together with the synchrotron radio-jets we found associated with the two persistent hard X-ray sources in the Galactic Centre region (1E1740.7−2942 and GRS1758−258, refs 17, 18 and 18, 19, respectively) suggest that, irrespective of the masses of the collapsed objects, sources of hard X-rays and γ-rays usually eject clouds of plasma at relativistic velocities. Therefore one can expect to find ejecta with superluminal expansions not only in distant quasars, but also in high-energy sources of stellar mass. □

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